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REVEGETATION AFTER FOUR STAND-REPLACING FIRES IN THE LAKE TAHOE BASIN

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ABSTRACT

Low and moderate intensity surface fires have been accepted as a natural and beneficial part of the upper montane mixed conifer forests in the northern Sierra Nevada, both in terms of reducing risk of crown fires and improving the ecological health of forests. Stand-replacing fires have not generally been considered ecologically significant, in part because they have been assumed to be historically unimportant. However, high intensity stand-replacing fires did occur prior to fire suppression and may have affected vegetation structure more than previously thought.

The occurrence of an extensive, pre-suppression, stand-replacing fire at the south end of Lake Tahoe on Angora Ridge was supported using historical evidence, aerial photographs, and stand age analysis. Data was gathered on the structure and composition of current vegetation on Angora Ridge and three subsequent stand-replacing fires using randomly selected plots. The post fire vegetation on these sites were compared in regard to species diversity, fuel accumulation, stand density, and composition.

Results indicate that a long period of herb and shrub domination occurred on Angora Ridge after the 1890's fire. The treeless period was followed by simultaneous recruitment of fir and pine. The sites of the three later fires have developed little forest canopy up to the present, and currently remain dominated by shrubs and small trees. While surface fuel accumulation and the density of standing dead trees were higher on Angora Ridge than on the other fire sites, species diversity was lower.

The prevalence of small, low intensity, surface fires in the Sierra Nevada before European settlement has been widely accepted (Kilgore 1981; Boyce 1921; Show and Kotock 1924). The exclusion of fire through suppression has resulted in a number of structural and compositional changes to forests throughout the Sierra Nevada, including the Lake Tahoe Basin. These changes include an increase in fuel load (Lunan and Habeck 1973; Minnich 1983, 1989; Wagel and Eakle 1979); a reduction in species richness (Baker 1992; Bock et. al. 1978; Murray 1992); and changes in species composition. Shade tolerant and non-fire resistant species such as *Abies concolor* (Gordon & Glend.) Lindley (white fir) tend to increase in dominance (Lunan and Habeck 1973; Phillips and Sure 1990), while species that require disturbance for germination, and tend to be more fire resistant, such as *Pinus jeffreyi* Grev. & Balf. (jeffrey pine) and *P. ponderosa* Laws. (ponderosa pine) decrease in frequency. The high density of forest stands that results from total fire suppression may also be a contributing factor in the tree mortality presently occurring in the Lake Tahoe Basin.

Low intensity surface fires are presently being used to reduce surface fuel and repress the development of understory in the forests around Lake Tahoe. The California Department of Parks and Recreation has been using prescribed surface fire on 10 to 40 ha per year in Lake Tahoe area parks to reduce fuel loading and enhance wildlife habitat (Rice 1988, 1990; Walter 1992). The USDA-Forest Service has used non-broadcast techniques such as machine and hard-pile burning for fuel reduction on 80–360 ha per year in the Lake Tahoe Basin (Swanson 1993). The importance of fire is also being considered in its relation to management of Lake Tahoe Basin forest ecosystems by the Tahoe Regional Planning Agency (TRPA) Forest Health Consensus Group (Swanson 1993; Sweeney 1993).

Concern about the ecological condition of the forested lands surrounding Lake Tahoe has been growing in recent years due to the visible decline of a large number of forest trees. This decline can be attributed to a number of factors, including an extended drought coupled with species conversion from drought tolerant pine to drought susceptible fir, high forest density, and the activity of bark beetles (Wenz and DeNitto 1983; Williams et al. 1992). Recent bark beetle outbreaks, though these beetles are a natural part of affected ecosystems, have resulted in unprecedented interest and commitment by both private citizens and public agencies toward the development of management policies and goals for the Lake Tahoe Basin forests. The TRPA Forest

TABLE 1. FIRE AREA CHARACTERISTIC. The forest type for all four fire areas was upper montane mixed conifer. The designations ABCO and PIJE stand for the dominant tree species on those sites, *Abies concolor* and *Pinus jeffreyi* respectively.

	Angora Ridge	Cathedral Creek	Cascade Lake	Luther Fire
Date	~1890	1937	1978	1987
Hectares	100	21	6.5	8
Elevation	1950–2190	1950–2190	1950–2190	2010–2190
Soil type	Meeks-Talac	Meeks-Talac	Meeks-Talac	Meeks-Talac
Forest type	ABCO	ABCO	PIJE	ABCO

Health Consensus Group, which includes private land owners and representatives of public agencies, has concluded that the forests should be managed toward their pre-European state (Swanson 1993; Sweeney 1993).

The historical occurrence of low and moderate intensity surface fires in Sierra Nevada montane forests is well accepted. However, due to their rarity larger and more intense stand-replacing fires, as defined by Romme (1980), have not been considered an important ecological factor in the evolution of these forests. Though it is true that surface fires were much more common than stand-replacing fires before European settlement and fire suppression, stand-replacing fires did occur (Kilgore and Taylor 1979) and their effect on forest structure may have been profound (Agee 1974). For example, recruitment of species that have high light requirements for seedling establishment is increased by stand-replacing fires through the opening of large canopy gaps. Habitat heterogeneity and species diversity may also be increased by crown fires (Baker 1992; Minnich 1983, 1989). In addition, gaps exceeding 10 ha caused by crown fire may be important in determining the structure and composition of the Sierra Nevada forests. Therefore, stand-replacing fires must be considered in understanding pre-European disturbance regimes.

This paper presents the findings in a study focusing on four stand-replacing fires in the south Lake Tahoe area. Our purpose is to demonstrate the existence of a stand-replacing fire that occurred prior to systematic fire suppression and to determine the development of vegetation after such fire.

FIG. 1. Angora Ridge taken from Upper Angora Lake in 1917 (Scott 1973). The southeast side of the ridge, and the denuded fire area is clearly visible.

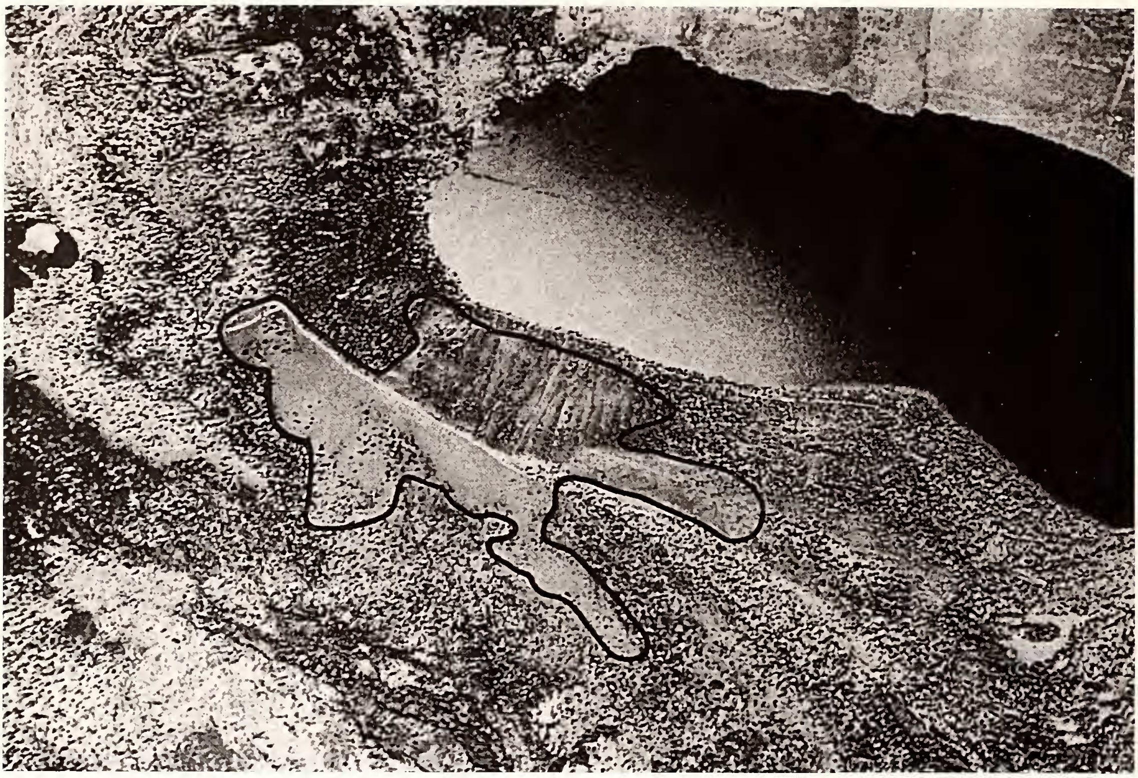

FIG. 2. This is the earliest available aerial photograph of Angora Ridge taken in July 1940. The fire area is clearly visible particularly on the south east side. The area appears to be dominated by shrubs.

METHODS

Location of study sites. The location and perimeter of four stand-replacing fires (Table 1) were determined through interviews with USDA Forest Service fire management personnel (Swanson 1993) and long-term residents of the area (Craven 1993; Gwinn 1993; Hildinger 1993), and through interpretation of historical and aerial photographs (1917–1983) (USDA-For. Serv. aerial photos).

The Angora Ridge Fire burned approximately 100 years ago, covered approximately 100 ha, and was located on both sides of Angora Ridge between the present location of the Angora lookout tower and lower Angora Lake. The fire ran from 1950 to 2190 m in elevation burning both the northwest and the southeast sides of Angora Ridge. The area's vegetation is currently dominated by a *Abies concolor-Pinus jeffreyi* mixed conifer forest type with *Calocedrus decurrens* (Torrey) Florin (incense cedar) included at the lower elevations, *Abies magnifica* Andr. Murray (red fir) becoming more prominent at higher elevations, and occasional occurrences of both *Pinus monticola* Douglas (western white pine) and *P. contorta* ssp. *murrayana* (Grev. & Balif.) Critchf. (lodgepole pine).

The Cathedral Creek Fire burned in 1937, covered approximately 21 ha, and was located in the Cathedral Creek drainage on the southeast slope above Fallen Leaf Lake, from 1950 to 2190 m in elevation. The same forest type dominates the area surrounding both fires, and both have soils of the Meeks-Tallac formation type (USDA 1974).

The Cascade Lake Fire burned in 1978, covered approximately 6.5 ha and was located on the southeast slope above Cascade Lake, from 1950 to 2190 m in elevation. The forest type surrounding this fire is similar to those above with more abundant *Pinus jeffreyi.*

The Luther Fire burned in 1987, covered approximately 8 ha, and was located on the northwest slope above Christmas Valley, from 2010 to 2190 m in elevation. Vegetation and soil types are similar to those in the other three fire areas.

Sampling techniques. Stand structure data was collected using 10 m by 20 m rectangular plots that were randomly selected along elevational gradients and distance from center of site within each study site. Within each plot slope, aspect, elevation, and forest type were recorded as well as information on size and identification of all live and dead standing trees present. The number of seedlings (trees less than 61 cm in height) and saplings (trees less than 10 cm in diameter) of each species were also recorded. Canopy cover was determined for the four cardinal directions at the center of each plot with a spherical densiometer. Fuel load was determined

FIG. 3. This 1983 photograph shows Angora Ridge in a state similar to its present condition, with high density forests on both sides of the ridge.

using a natural forest residue photo series (Blonski and Schramel 1981). Stand age was determined by taking a core sample from the largest tree of each species present on each plot.

Three 1.8 m diameter circular nested plots were used within each 10 m by 20 m rectangular plot to sample herbaceous and shrub species. For all shrubs present, cover class was determined using a standard cover scale (Daubenmire 1959, 1968). The presence of all herbaceous and shrub species on 1.8 m plots was recorded.

Stand structure analysis. Data collected on 65 timber plots and 195 herbaceous-shrub plots yielded the total and relative frequency and density of each tree species, the total and relative frequency and density of standing dead trees, the total and relative frequency and density of seedlings and saplings of each species, the average canopy cover for each study site, the average percent cover of each shrub species, the average fuel load (metric tons/ha) for each study site (Blonski and Schramel 1981), and three measures of species diversity (species richness, species evenness, and the Shannon diversity index).

RESULTS

Interpretation of aerial photographs. Aerial photographs of the Angora Ridge indicate that a long interval occurred before tree cover developed following the fire in the 1890's. There is little or no tree canopy visible in aerial photographs in the fire area before 1952. Historical photographs taken in 1917 (Fig. 1) and aerial photographs taken in 1940 (Fig. 2) show that the post-burn was dominated by brush fields.

Aerial photographs taken in 1952 and 1966 show the gradual development of tree canopy on Angora Ridge. By 1976 (Fig. 3) aerial photographs indicate that a significant forest canopy has developed but there are still areas of shrub domination.

Stand age. Tree ages for the dominant tree on each plot ranged from 21 to 95 years on Angora Ridge. The modal age was 70 years for all species with no significant difference in age between *Abies concolor, A. magnifica,* and *Pinus jeffreyi.* This is consistent with the existence of a 100 year old stand-replacing fire. The 30 year delay in tree recruitment is consistent with shrub domination during the same period. As sheep grazing was common in the study area during the period in question it may have influenced vegetation recruitment patterns, however, the occurance of shrub domination on the Cascade Lake fire and Luther fire areas suggests that grazing is not necessarily a factor.

On the Cathedral Creek Fire area the dominant tree age on each plot ranged from 20 to 54 years

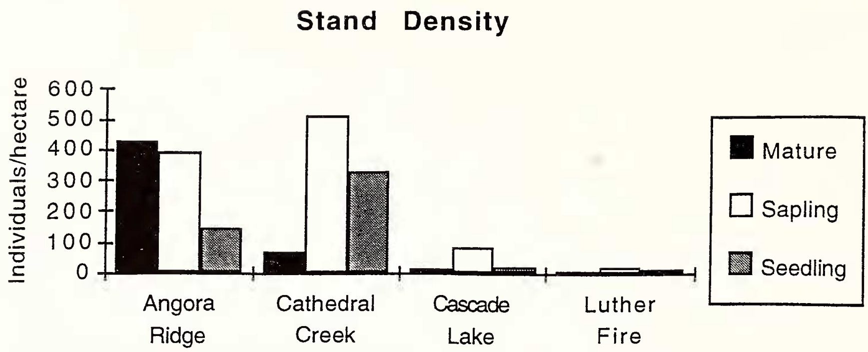

FIG. 4. Stand density.

with a modal age of 39 years. There was no significant difference in age between *Abies concolor* and *Pinus jeffreyi.* This result is consistent with a 56 year old fire.

Neither the Cascade Lake Fire area nor the Luther Fire area had enough tree recruitment to determine stand age through coring. Both areas are dominated by shrubs. Because of their recent occurrence, however, the age of the burns were easily determined through fire records and interviews with USDA Forest Service fire suppression personnel (Johnson 1993).

None of the sites studied received artificial replanting treatments so that stand age reflects natural recruitment and development.

Structural analysis. The density of mature trees was much higher on the Angora Ridge Fire site than on the Cathedral Creek, Cascade Lake, and Luther Fire sites (Fig. 4). This difference in the density of mature trees was associated with other structural differences such as canopy and shrub cover. Canopy cover averaged 72% on Angora Ridge and less than 10% on each of the other three fire sites. Shrub cover dominated these three sites (Cathedral Creek = 88%; Cascade Lake = 76%; Luther Fire = 87%) while Angora Ridge exhibited only 13% shrub cover. These results suggest that the balance between tree and shrub cover is a function of the time interval since fire and the ability of trees, once they become established, to shade out shrubs.

A difference in species diversity occurred between the Angora Ridge and the other three fire areas as is indicated by species richness counts and the Shannon diversity index (Fig. 5) which were higher on the three younger sites. Though the number of tree species is relatively consistent on all of the sites, the abundance of herbaceous and shrub species was lower in the older fire area. This is due primarily to increased shading resulting from greater tree canopy on that site.

The accumulation of fuel also varied between the older site and the three younger sites with the highest fuel accumulation occurring on Angora Ridge (Fig. 6).

Results indicate a pattern of vegetation development consistent with conventional models of post-fire succession in mixed conifer forests (Lyon and Stickney 1976; Kercher and Axelrod 1984). However, the proportional abundance of the two major genera of trees, *Abies* and *Pinus,* was about the same for Angora Ridge, Cathedral Creek, and the Luther fire (Table 2) with white fir clearly the dominant species. In the Cascade Lake Fire area, however, *Pinus* was clearly dominant. The relative dominance of *Abies* and *Pinus* on these sites is likely the result of seed availability rather than a result of post-fire competition and succession. This is further demonstrated by a comparison of the relative density of mature fir and pine to seedlings and saplings (Table 2). The earliest recruitment of fir ap-

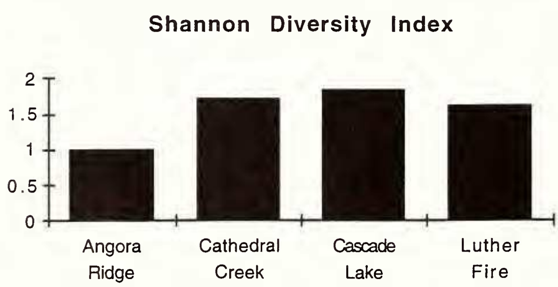

FIG. 5. Shannon diversity index.

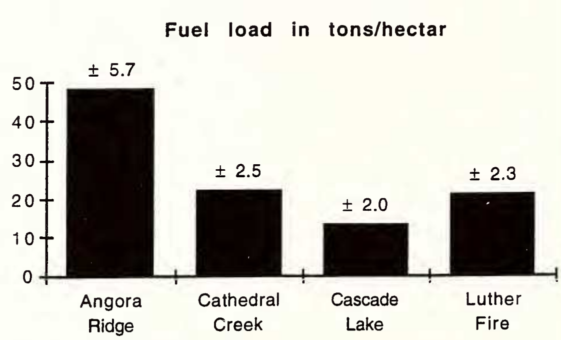

FIG. 6. Fuel load.

TABLE 2. RELATIVE DENSITY. ABMA = *Abies magnifica*, ABCO = *A. concolor*, PIJE = *Pinus jeffreyi*, PICO = *P. contorta* (ssp. *murrayana*).

	Angora Ridge			Cathedral Creek			Cascade Lake			Luther Fire		
Species	Mat	Sap	Seed	Mat	Sap	Seed	Mat	Sap	Seed	Mat	Sap	Seed
ABMA	3.5	2.3	4	—	1	—	—	—	—	—	—	—
ABCO	89	93	96	79	83	99	—	4.5	—	—	86	83
PIJE	8.5	4.7	—	21	16	1	—	91	100	—	14	17
PICO	—	—	—	—	—	—	—	4.5	—	—	—	—

pears to have coincided with the earliest recruitment of pine. There does not appear to be a requisite period of pine domination on these sites as was described for a similar site in the Sierra Nevada (Bock and Bock 1969; Bock et al. 1976). The continuous regeneration of *A. concolor* found in this study is comparable to that found by Conard and Radosevich (1982).

Mortality. The total density of dead trees and the relative mortality of individual species may be useful in predicting the future direction of vegetation change. Clearly the density of dead to live trees were much higher on the Angora Ridge than on the other three sites (Fig. 7) suggesting that mortality may be connected to stand density. The mortality of *A. concolor* was much higher than that of any other species resulting from the high density of this species. All trees that were recorded as dead on both fire sites showed evidence of bark beetle activity.

CONCLUSIONS

The Angora Ridge fire occurred at a time before the implementation of systematic fire suppression (Craven 1993; Gwinn 1993; Hildinger 1993). The existence of this fire and the ecological information collected within its perimeters indicates that not only did stand-replacing fires exist before fire suppression, but that the process of forest development after such fires can be lengthy, including a long period with minimal forest canopy cover. In addition, results point to a number of other interesting conclusions including a lack of a post-fire pine domination period on the sites studied, higher species diversity on the more recent fire sites, and higher fuel accumulation on the oldest fire site.

Simultaneous recruitment of pine and fir occurred on the four fire sites during their post-fire periods. Fir and pine did not follow the traditional successional sequence after large fires that usually includes a period of pine domination followed by increasing fir domination (Bock and Bock 1969; Bock et al. 1976; Lyon and Stickney 1976; Kercher and Axelrod 1984). It appears that there was no obligatory period of post-fire pine domination in the study areas, and that fir regenerated with as much facility as pine.

The higher species diversity on the more recent fire sites is important in that diversity seems to decline as canopy cover increases. This supports the notion that in some communities diversity has an inverse relationship to secondary successional development of forests after fire (Shafi and Yarranton 1977).

Higher fuel accumulation and a high density of standing dead on the older fire site suggests that the long fire-free interval has increased the probability of another high intensity fire.

In the quest to determine the proper role of fire in the forest management scheme in the Tahoe Basin, stand-replacing fires need to be understood as part of the pre-European fire regime. In addition to periodic surface fires, stand-replacing fires have been instrumental in the formation of canopy gaps, and the maintenance of habitat heterogeneity and species diversity. Including stand replacing-fire as a part of forest management in the Lake Tahoe Basin may be unpopular socially and politically, and difficult to implement. However, suppression of all

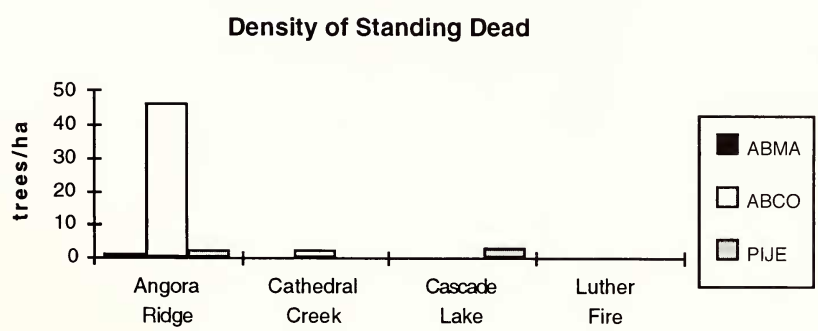

FIG. 7. Standing dead.

stand-replacing fires, in the long run, may be more costly than their careful management.

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